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## **Crop Management – how does it affect the performance of intercrops?**

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### **Summary**

Intercropping typically results in a higher yield than those of the individual crops. While appropriate management is vital to get the best performance from any crop, this is especially true for mixtures where strategies must account for the management of two contrasting crops and also for any interactions between them. However, developing management recommendations for intercrops is complex because of the high degree of variation in the findings of published studies and the number of different management strategies available, which depend on the components of individual mixtures. The aim of this work was to examine the effects of management options of cereal species and variety, and pea variety, on the relative performance of cereal/pea intercrops, with a longer-term objective of incorporating them in more diversified and resilient agro-ecological arable cropping systems less dependent on external inputs.

**Key words:** Wheat, Barley, Oats, Pea, land equivalent ratio, crude protein

### **Introduction**

The need to sustainably intensify crop production and to increase the production of protein are two of the main challenges facing European agriculture. One cropping system that potentially addresses both issues is intercropping, the simultaneous cultivation of two or more crops on the same area of land at the same time. On a global scale, non-maize based intercrops tend to be 20% more productive than sole crops for a given land area (Li *et al.*, 2020), thus addressing the need for increased production from existing agricultural land. If the intercrop contains a N-fixing legume then the N fertiliser requirements of the other intercrop component will be reduced by 19% (Li *et al.*, 2020). Furthermore, the legume component will help increase the overall protein offtake of the crop, particularly if the legume grown is a grain legume.

In European agriculture the predominant intercropping system is a combination of a cereal with a grain legume (Voisin *et al.*, 2014) and the commonest combination is barley (*Hordeum vulgare*) grown with pea (*Pisum sativum*) (Hauggaard Nielsen *et al.*, 2009). These systems are characterised by relatively low inputs but are also relatively low yielding. They are grown in rows as mixtures that are sown and harvested at the same time and are particularly common in organic production systems (Bedoussac *et al.*, 2015).

A key practical challenge to increase the use of intercrops in Europe is to design optimised and locally adapted management practices for species mixtures. While appropriate management is vital to get the best performance from any crop, this is especially true for mixtures where strategies must account for the management of two contrasting crops and also for any interactions between them. However, developing management recommendations for intercrops is complex because of the high degree of variation in the findings of published studies and the number of different management strategies available. Perhaps the most important and fundamental of these is the choice of species to intercrop, and within that, the choice of variety.

Existing reviews of the effects of management on intercrops are very broad in the types of intercrops that they consider (Yu *et al.*, 2016; Pelzer *et al.*, 2014). While both studies provide valuable insights into overarching management principles, they inevitably contain a large degree of variation that masks some of the less distinct trends. An approach that appraises studies on a more restricted intercrop combination grown under one climatic regime might produce more specific information on management effects.

One common feature across the majority of the intercropping literature is the use of land equivalent ratio (LER) as an indicator of performance. LER is the sum of partial LERs (pLER). These are the ratios of the yield of one species in an intercrop to its yield as a sole crop, and have been used as an indicator of the relative performance of each component of an intercrop. As such it provides an estimate of the efficiency of land use with an LER greater than one indicating that the intercrop uses land more efficiently than a sole crop.

This paper presents a literature review of the effects of selected management factors on the performance of cereal/pea intercrops under cropping conditions relevant to Europe. The management factors selected were variety of pea, and species and variety of the cereal components of the intercrop. The cereals selected were barley, wheat (*Triticum aestivum*) and oats (*Avena sativa*). LERs for both grain yield and crude protein (CP) yield are used as indicators of performance of the intercrops relative to their sole cropped species. Results are discussed in relation to using intercrops as part of more diversified and resilient agro-ecological arable cropping systems less dependent on external inputs.

## Materials and Methods

### *Paper selection*

The “all database” option in Web of Knowledge (WoK) was used to identify the papers for review, using the search terms:

((("cereal pea" OR "pea cereal" OR "pea with cereal" OR "cereal with pea" OR "cereal and pea" OR "pea and cereal") AND (intercrop\* OR mix\* OR bicrop\* OR bi-crop\* OR (bi AND crop)) NOT (genomi\* OR tropical OR africa\*))

Where cereal was substituted by barley, oat and wheat.

The date of the search was 25 June 2019 and after removing duplicates 343, 255 and 363 barley, oat and wheat papers respectively were identified as potentially relevant. To be relevant for the study, the papers must contain data on field experiments that assess the effect of management on cereal/pea intercrops. Thus, literature reviews, pot experiments and papers which focused solely on modelling were excluded. The studies must also be relevant to European growing conditions, although not necessarily have taken place in Europe. At this stage the papers were retained or rejected after reading the title and/or abstract. After scanning the titles and abstracts, 72, 71 and 64 papers were identified as potentially containing information on the effect of management on barley-pea, oat-pea, wheat-pea and intercrops respectively. After reading the papers, 19, 10 and 6 papers contained extractable data for the barley, oat and wheat intercrops respectively (see Table 1).

### Analysis

The land equivalent ratios (LERs) were calculated for the experiments for which the yields of the individual sole crop and the components of the intercrop were available. To calculate LERs, all yield data were converted to tonnes per hectare dry matter. The same process was used to calculate the CP land equivalent ratios (CPLERs). Protein data in most papers was usually derived from analysis of N content multiplied by 6.25. Wheat data from Pelzer *et al.* (2016) was originally converted using a factor of 5.7 but to allow better comparisons here it has been recalculated using a factor of 6.25. Gronle *et al.* (2015) used protein contents derived from near infrared (NIR) analysis. The data manipulation was all performed in R (R Development Core Team, 2008), and the ggplot2 package (Wickham, 2016) has been used to create the graphics.

Table 1. *The number of data records captured from each of the selected references*

Author	Number of Records	Author	Number of Records
Barillot <i>et al.</i> , 2014	7	Lithourgidis <i>et al.</i> , 2011	10
Baxevanos <i>et al.</i> , 2017	15	Mason & Pritchard, 1987	6
Chapagain, 2014a	5	Monti <i>et al.</i> , 2016	26
Chen <i>et al.</i> , 2004	12	Musa <i>et al.</i> , 2010	5
Corre-Hellou <i>et al.</i> , 2006	15	Neugschwandtner <i>et al.</i> , 2014	10
Dordas <i>et al.</i> , 2012	7	Neumann <i>et al.</i> , 2007	52
Ghaley <i>et al.</i> , 2005	8	Ogorek <i>et al.</i> , 2019	21
Gilliland & Johnston, 1992	18	Pappa <i>et al.</i> , 2012	5
Gronle <i>et al.</i> , 2015	24	Pelzer <i>et al.</i> , 2012	75
Hauggaard-Nielsen <i>et al.</i> , 2001	76	Pelzer <i>et al.</i> , 2016	16
Hauggaard-Nielsen <i>et al.</i> , 2006	12	Podgorska-Lesiak <i>et al.</i> , 2013	45
Hauggaard-Nielsen <i>et al.</i> , 2008	28	Rauber <i>et al.</i> , 2001	24
Izaurrealde <i>et al.</i> , 1990	19	Robinson, 1960	42
Jannoura <i>et al.</i> , 2014	9	Salawu <i>et al.</i> , 2001	4
Jensen, 1996	24	Strydhorst <i>et al.</i> , 2008	13
Kontturi <i>et al.</i> , 2011	90	Tortorella <i>et al.</i> , 2013	7
Kwabiah <i>et al.</i> , 2005a	9	Tsialtas <i>et al.</i> , 2018	15
Lauk & Lauk, 2008	21	Uzun & Asik, 2012	15
		Grand Total	790

## Results

### Summary of the data

The data capture exercise generated 790 individual data records, where each record was a unique combination of site, year, cereal and/or legume species, seed ratios, sowing pattern and N fertiliser.

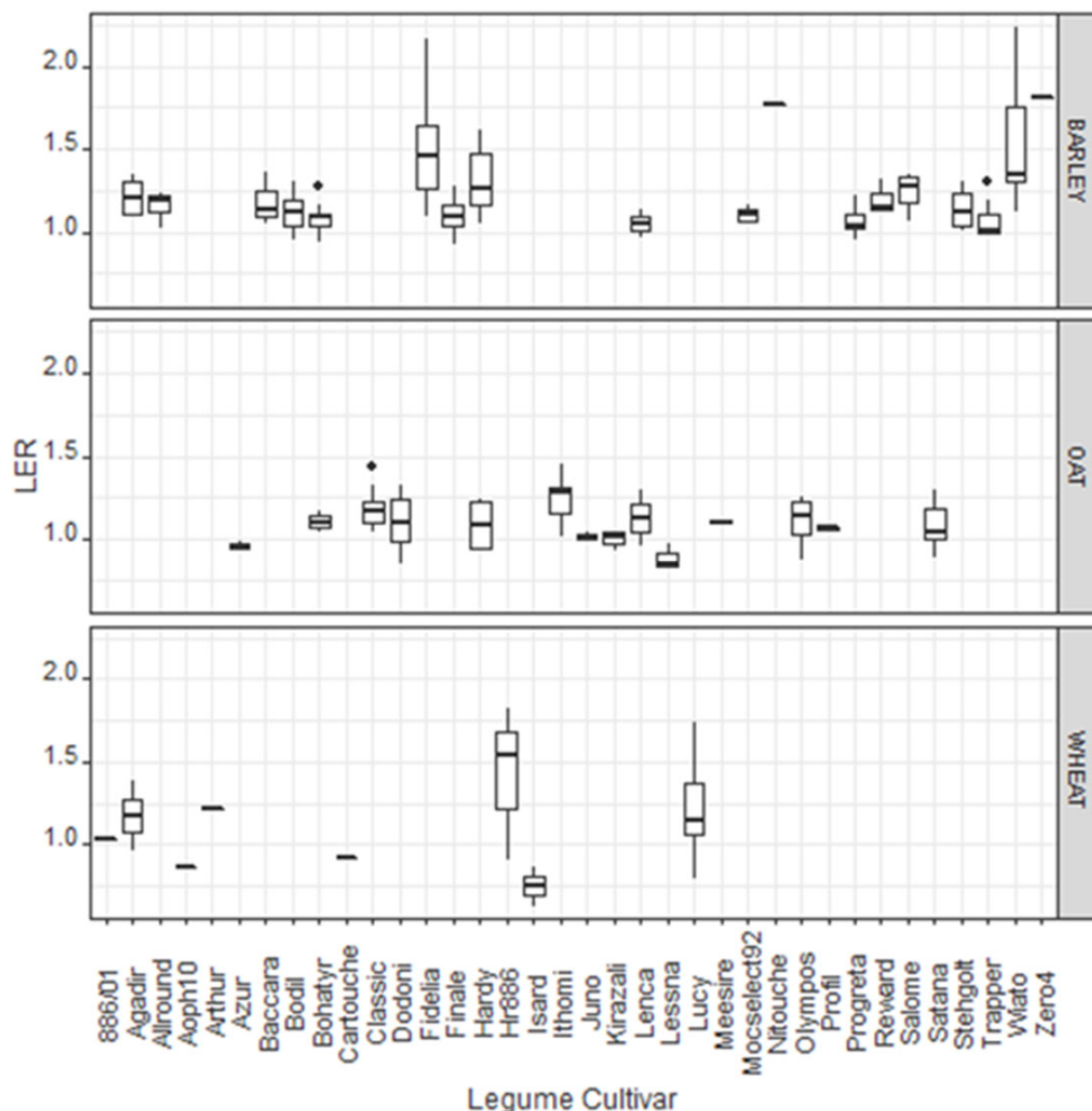


Fig. 1. Boxplots summarizing the LER of the intercrops for barley, oat and wheat by legume variety. The solid horizontal line within a box represents the median value.

This includes sole crops (319 records) and intercrops (471) and the number of records captured from each of the 36 selected papers is shown in Table 1. The majority of records related to intercrops of pea with oat (194), barley (184) or wheat (63), but other cereal/grain legume (30) intercrops were also captured where these were from studies that compared their management. Data came from studies in 14 countries, 11 in Europe (387 records), sown between 1955 and 2012. Most records reported data from 1 year (325) but some averaged data over 2 (92) or 3 (46) years. Where specified, the majority of records were from non-organic systems (321/366) and grown for the grain market (252/349) rather than for forage/silage. No N fertiliser was applied in just over one third of the records where the fertiliser input was specified. About 50% of records showed a low ( $<65 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ ) level of N fertilisation and about 10% received a higher amount ( $>65 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ ).

Within the database, for experiments receiving a low level of fertilisation, there were 36 varieties of peas that have been grown with either barley, oats or wheat (Fig. 1). Typically, the intercrops of barley and pea had a higher median LER (1.14) than either the oats (1.09) or wheat (1.10). However, the range in the wheat LERs was greater than the oats. In contrast, the median LERs for CP were higher for wheat (1.31) than oats (1.18) or barley (1.15).

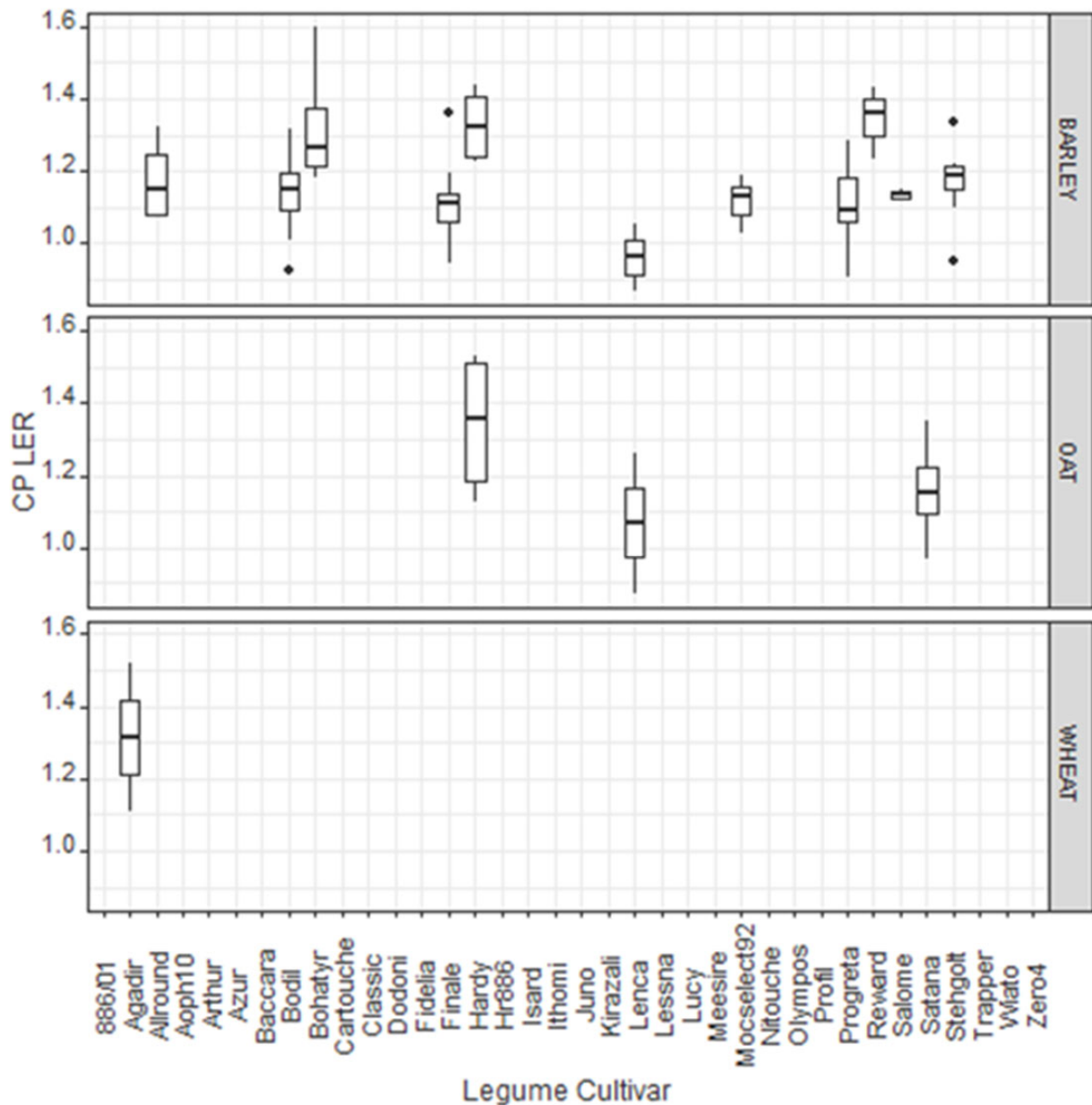


Fig. 2. Boxplots summarising the CPLER of the intercrops for barley, oat and wheat by legume variety.

Eighteen of the pea varieties have been paired with barley, 14 with oats and eight with wheat. The median LER for the pea component paired with barley was always greater than 1. However, the results for oats and wheat were more variable as the LER for pea variety “Lessna” paired with oats was  $<1$ , and the performance of three of the pea varieties paired with wheat was worse than the sole crop. There were fewer records for CPLER (Fig. 2). Nevertheless, with the exception of “Lenca” paired with barley, the CPLERs were greater than 1. There were 16, 10 and six varieties of barley, oats and wheat respectively grown with peas (Fig. 3). The cereal varieties showed more variability in the LERs compared to the legume varieties (Fig. 3). The results indicate that the oat variety “Effektiv” and the wheat variety “Cezanne” when paired with peas produced a lower yield than the sole crops. In the case of CP, only the barley variety “Chapais” had an LER  $<1$  (Fig. 4).

## Discussion

The main aim of this work was to assess the impact of management factors on the potential for pea/cereal intercrops to contribute to more diversified and resilient agro-ecological arable cropping systems less dependent on external inputs. The management factors examined were perhaps the



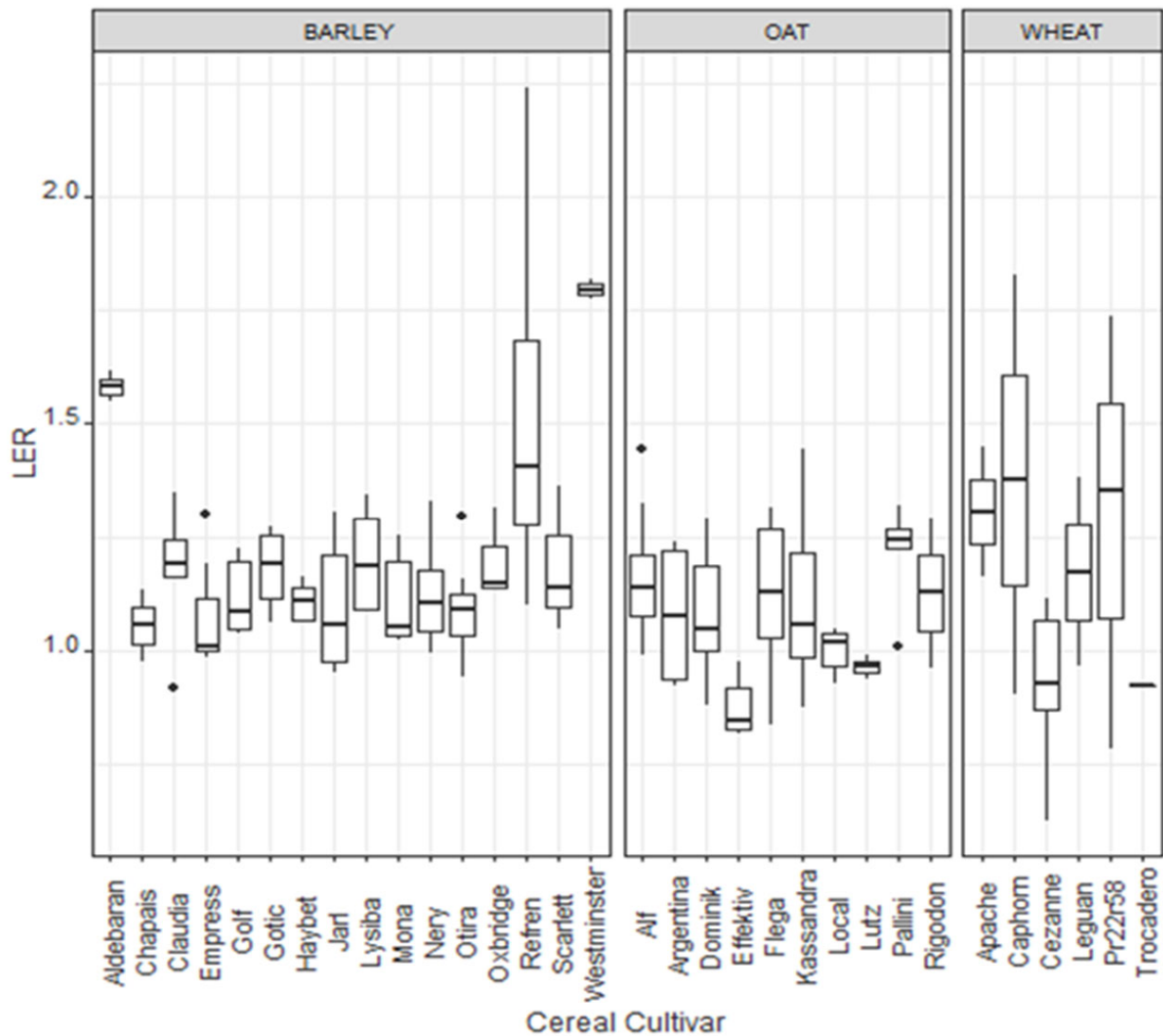


Fig. 3. Boxplots summarising the LER of the intercrops for barley, oat and wheat by cereal variety.

two most fundamental ones when cultivation of an intercrop is considered; choice of species to be grown and within that, what variety of each species. In the majority of cases the pea/cereal intercrops in this study were more productive per unit land area than their sole crops, thus meeting the objective of a more diversified system with reduced inputs. Across the different varieties of both peas and cereals there was a considerable range of LER values with just a few varieties of each showing values considerably above the median. This demonstrates the potential for further production increases and the characteristics of these varieties should be investigated to that end.

In addition to increased yield, the pea/cereal intercrops also showed increased CP production per unit land area, thus showing that intercrops have the potential to contribute to increased protein production in Europe. However, barley was the only cereal species with more than three sets of data for CP, indicating that more research is needed across the range of cereal species. Within barley there were again large effects of variety on CPLER and this variation appeared to be larger for barley variety than for pea. Thus, choice of barley variety may be the most important factor for these intercrops. The reason for this is not clear from this study, but may be related to the greater efforts made to improve nitrogen use efficiency in barley breeding programmes conducted under high-fertiliser-input conditions.

The analysis presented here has concentrated on choice of species and variety as essential management decisions. There are many other management factors that are likely to influence the performance of intercrops to a greater or lesser extent. The physical design of the system in terms of whether the two species are mixed at sowing or sown separately, sown in rows, strips or

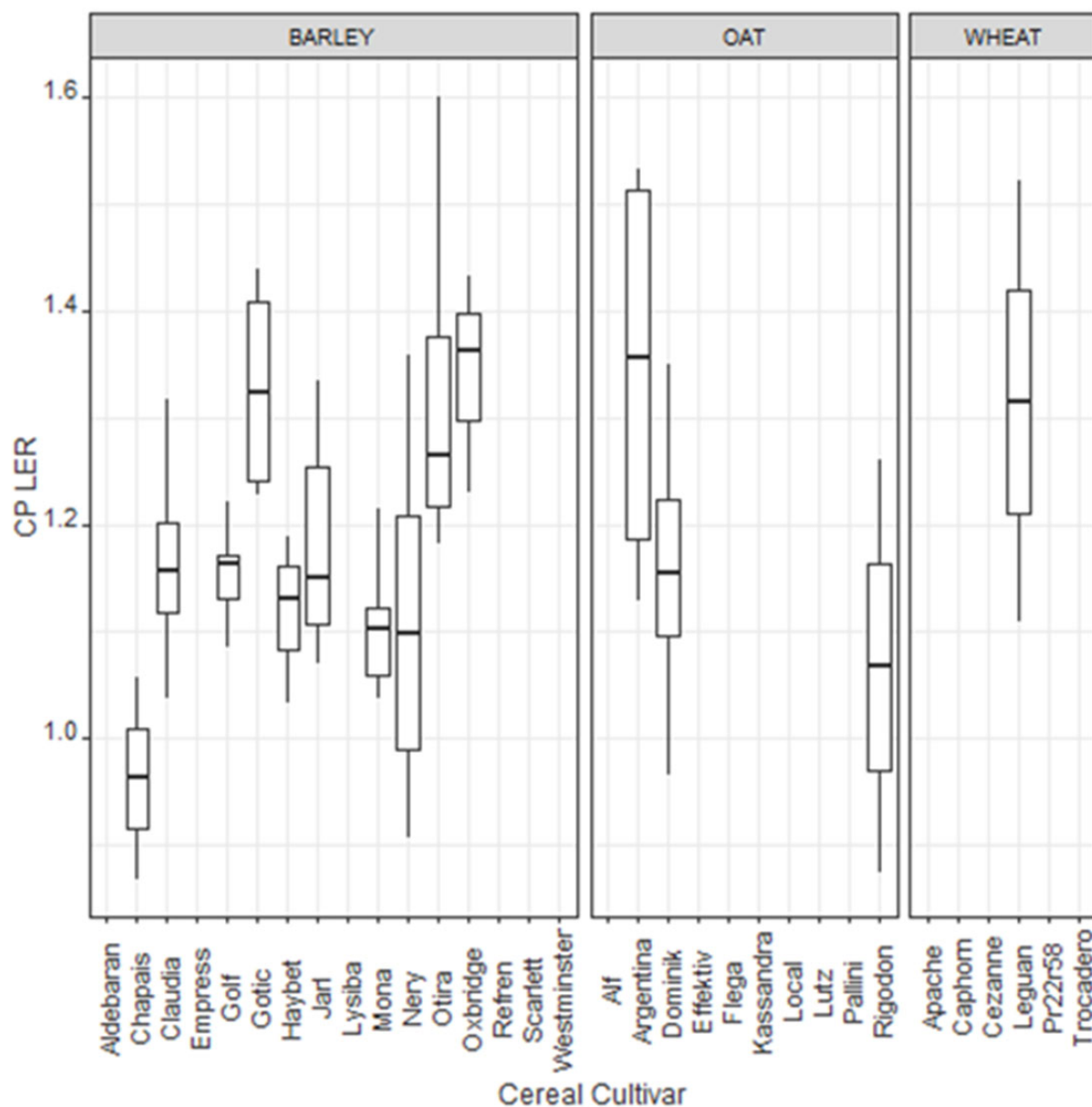


Fig. 4. Boxplots summarising the CPLER of the intercrops for barley, oat and wheat by cereal variety.

broadcast, and row spacing are all likely to be important considerations in a system so dependent on the physical interaction of the species. More conventional agricultural management factors are also likely to have an effect, such as the choice of sowing and harvesting dates, use of any fertilisers and crucially the choice of market for the harvested products.

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